Quick Study® ACADEMIC

ASTRONOMY

A COMPREHENSIVE GUIDE TO THE UNIVERSE

HISTORY OF ASTRONOMY

ANCIENT TIMES

A. **Stonehenge**, on the Salisbury Plain in southern England, was built in stages from about 2800 BC to about 1075 BC to observe the sun and the moon, and thus bring regularity to the builder's calendar.

B. **Big Horn Medicine Wheel**, an arrangement of rocks resembling a 28-spoke wheel in the Big Horn Mountains of Wyoming, was used as a calendar by the Plains Indians from about 1500-1700 A.D.

C. The **Caracol Temple** on the Yucatan peninsula is a 1000-year-old astronomical observatory.

THE ASTRONOMY OF GREECE

Greek astronomy was based on the astronomy of Babylon and Egypt, which was heavily influenced by astrology.

A. **Plato** (427-347 BC) argued that the reality we see is only a distorted shadow of the perfect ideal form. Further, he taught that the most perfect form was the circle.

B. **Aristotle** (384-322 BC) suggested two reasons to believe the Earth was round. First, when a ship came over the horizon, the mast was initially visible, then the deck, and then the entire ship. Second, he observed that the Earth's shadow on the moon during a lunar eclipse was curved. Only an Earth which was curved could produce this. He also proposed a geocentric (Earth-centered) solar system.

C. **Aristarchus** (c. 200 BC) proposed a theory that the Earth rotated on its axis and orbited about the sun.

D. **Eratosthenes** (c. 200 BC) devised a method for determining the Earth's circumference to within 5% of the currently accepted value.

E. **Hipparchus** (c. 150 BC) discovered precession and made the first catalog of stellar magnitudes.

F. **Ptolemy**

1. Claudius Ptolemaeus (Ptolemy)(c. 100 AD) lived and worked in the Greek settlement of Alexandria (now Egypt). He ensured survival of Aristotle's geocentric universe theory by fitting it to a sophisticated mathematical model.
2. Ptolemy found that simple spheres were not enough to account for the motions of the planets. Planets sometimes move faster, sometimes slower, and occasionally appear to slow to a stop and move backward over a period of days or months. This is called **retrograde motion**. He accounted for this motion by placing the planets on small circles (**epicycles**) that moved along larger circles (**deferents**).
3. His work was published in 140 AD in what is now known as the ***Almagest***.

PIONEERS OF ASTRONOMY

COPERNICUS

A. Nicolas Copernicus (1473-1543) lived and worked in what is now Poland. Because of his long and abiding relationship with the Christian Church, he hesitated to publish his revolutionary ideas in astronomy, so he distributed an unsigned pamphlet in 1507, which outlined his hypothesis of a **heliocentric** (sun-centered) solar system.

B. Copernicus worked on his book, ***De Revolutionibus***, over a period of many years. It was published in 1543, when he realized he was dying.

C. The Copernican system explained retrograde motion without epicycles, and was elegant and simple compared to the Ptolemaic system.

TYCHO BRAHE

A. Tycho Brahe (1546-1601) was a Danish nobleman. He developed new and better instruments for viewing the stars, sun, moon, and planets. (Telescopes had not yet been invented.)

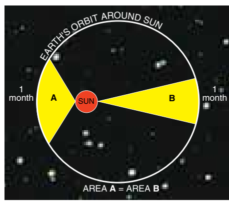
B. Brahe published his results in what are now called the ***Rudolphine Tables*** (after his patron, Holy Roman Emperor Rudolph II). To assist him, he hired other mathematicians and astronomers, including Johann Kepler.

KEPLER

A. Johann Kepler (1571-1630) was born in what is now southern Germany. Ten days before Brahe died, in 1601, he asked that Kepler be made imperial mathematician. Upon Brahe's death, Kepler inherited his records.

B. Using Brahe's tables of the positions of the planets, Kepler was able to deduce his three laws of planetary motion:

1. The orbits of the planets are ellipses with the sun at one focus.
2. A line from the planet to the sun sweeps over equal area in equal time.
3. A planet's orbital period squared, is proportional to its average distance from the sun cubed, where P is the period in years, and A is the distance in AU. One AU is the distance from the earth to the sun, and is equal to 93 million miles. $\mathbf{A^3 = P^2}$



C. Kepler's laws are empirical (based on observations). They do not describe the causes of the motion; they only predict where the planets will be in the future.

GALILEO

A. Galileo Galilei (1564-1642) was born in Pisa, Italy. Galileo was the first scientist to make *systematic* use of the telescope in looking at the heavens.

B. Galileo's discoveries with the telescope include:

1. The moon was not smooth; it had valleys and craters. This conflicted with the notion that all heavenly bodies were perfect spheres.
2. The Milky Way was made up of thousands of stars too dim to be seen with the unaided eye.
3. The discovery of Jupiter's moons lent credence to the Copernican model, as it was now recognized that objects other than the earth could have moons orbiting about them. These **Galilean moons** are Io, Europa, Ganymede, and Callisto, all satellites of Jupiter.
4. Galileo later observed that the sun had **sunspots** and rotated with a period of 25 days.
5. Galileo saw that Venus passed through phases similar to those of the moon. That meant it orbited around the sun, not the Earth.

C. Galileo published two major works, ***Sidereus Nuncius*** and ***Dialogue Concerning the Two Chief World Systems.*** The publication of the second of these created a storm of controversy. He was interrogated four times by the Inquisition, and in 1633 he was forced to recant his views of the heavens. Upon recanting, Galileo was put under house arrest until his death in 1642.

ISAAC NEWTON

A. Isaac Newton (1642-1727) was born in the English village of Woolsthorpe. In 1665-1666, when Black Plague closed Cambridge where he was studying, he returned to Woolsthorpe, and there derived his famous three laws of motion. These laws of motion were found to work for objects in the heavens, as well as objects on Earth, thereby making Newton the first astrophysicist. His **laws of motion** are:

1. A body continues in motion in a straight line at constant speed, or remains at rest, unless it is acted upon by some external force.
2. A body's change of motion is proportional to the force on it and the direction of the force, $\mathbf{F = ma}$
   F = Force **m** = mass **a** = acceleration.
3. When one body exerts a force on a second, the second body exerts an equal and opposite force upon the first.

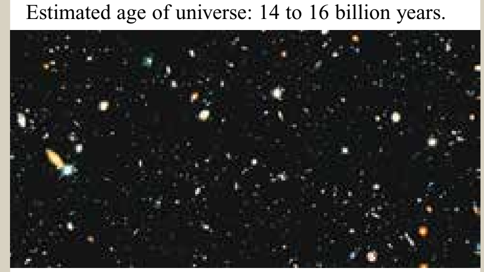
B. Newton distinguished between an object's mass, which is how much matter it contains, and its weight. A person who is on the moon is attracted by the moon's gravity less than that same person will be attracted to the Earth by Earth's gravity. That person's mass is the same in both places, but the weight is different. Weight is a force, mass is the amount of matter.

C. Newton determined that for the planets to orbit the sun in elliptical trajectories, they must be subject to a force that decreases proportional to the square of their distance from the sun. In addition, the force must be proportional to the masses of the sun and the planet. In equation form, this is stated by $F = \frac{G\,M\,m}{r^2}$

D. In the above, F is the mutual force of attraction between the planets, G is the **universal gravitational constant**, 6.67X10-11m2/kg s2, r is the distance between the sun and the planet, M is the mass of the sun, and m is the mass of the planet. This is the *Law of Universal Gravitation* because we can extend this equation to any two objects, in the universe. For example 'M' could be the mass of Jupiter, while 'm'could be the mass of its satellite Europa. Therefore all massive objects are gravitationally attracted to all other massive objects in the universe."

QUICK REFERENCE OF SPACE DIMENSIONS

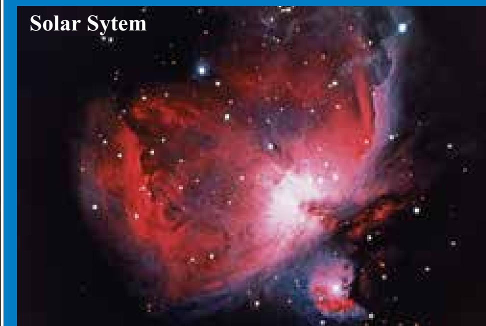
10 million trillion atoms in one cc of air at sea level.
1 atom per cm^3 in the void between stars.
1 atom per m^3 in the void between galaxies.
Earth is 5 billion years old and 7,921 miles in diameter.
Distance to our moon is 238,774 miles.
Distance to our sun is 93,150,000 miles = 1 AU.
Distance to Pluto's orbit varies between 26 to 52 AU.
Distance to nearest star, Alpha Centauri, is 4.3 LY
Speed of Light = 186,170 miles/sec. 1 AU = 8 minutes at S of L.
Light travels in 1 light year 5.9 trillion miles = 1 LY = 65,555 AU
Milky Way Galaxy is 100,000 LY wide and 1,000 LY thick.
Estimated number of stars in the Milky Way Galaxy: 400 billion +
Estimated number of galaxies in universe: 50 billion +
Estimated number of stars in universe: 5 billion trillion.
Estimated age of universe: 14 to 16 billion years.



This Hubble Telescope image of deep space reveals thousands of previously unknown galaxies in a sector of sky about the size of a grain of salt at arms length.

THE SOLAR SYSTEM

THE ORIGIN OF THE SOLAR SYSTEM



Solar Sytem

A. **The Solar Nebula Theory:** Our solar system was probably formed out of a spinning ball of gas. When the sun became luminous enough, the remaining dust and gas were blown away into space, leaving the planets orbiting the sun. This happened about 4.5 billion years ago.

B. The planets move around the sun in orbits that lie nearly in a common plane, and they all revolve about the sun in the same direction (counter-clockwise as seen from the North Pole).

C. By the process of condensation, the heavier elements condensed toward the hotter, inner part of the nebula, and the lighter, more volatile elements condensed further out. Therefore two distinct types of planets exist. The **Terrestrial** (Earth-like) planets, Mercury, Venus, Earth and Mars, are small, dense and rocky. The **Jovian** (Jupiter-like) outer planets, Jupiter, Saturn, Uranus and Neptune, are enormous gas giants and are larger, less dense and much colder.

D. As the solar nebula cooled, small aggregates of material called **planetisimals** began to accrue mass. The inner planetisimals accrued heavier material through condensation and the fact that the lighter material had been swept away by the solar wind. The planetisimals further out accrued lighter material. As the planetisimals grew larger, they began to act as vacuum cleaners ridding the solar system of debris eventually becoming the current planets.

E. The solar system is left with three types of debris from the solar nebula, asteroids, comets and meteoroids.

1. **Asteroids** are small rocky worlds. Most asteroids orbit the sun in a region between Mars and Jupiter called the **Asteroid Belt**. This belt is thought to be the remains of a planet that failed to form at a distance of 2.8 AU from the sun. There are about 200 asteroids larger than 60 miles in diameter, about 200 larger than 6 miles, and 500,000 larger than 0.6 miles.
2. **Comets** are large dirty snowballs. They consist of three parts. The *nucleus* is a ball of frozen water and carbon dioxide, and is usually a few dozen Km in diameter. The *coma* is the bright area surrounding the nucleus, and may be as large as Neptune. The *tail* is a luminous trail of debris left behind as the comet melts. As a comet falls into the sun from the **Oort Cloud** or the **Kuiper Belt**, it steadily becomes warmer. At about the same distance from the sun as Jupiter (about 5 AU), it begins to melt. The debris it leaves behind behaves similarly to exhaust from a car on a windy day. If there is no wind, the exhaust trails out behind the car. But if it is very windy, the exhaust will go in the direction of the wind, no matter how fast the car is going.

Comet

A comet travels at about 30 Km/s. The solar wind, which is continuously emitted from the sun, gusts from 300 to 800 Km/s. The tail of the comet is therefore always blown away from the sun by the solar wind, which also causes it to be luminous.

3. A **meteorite** is a space object (a piece of debris, a pebble, a grain of sand) that survives its plunge through the atmosphere to hit the Earth. Before it hits the Earth, it is called a meteoroid. A **meteor** is the streak of light across the night sky that one sees as the object burns up in the atmosphere. **Meteor showers** are events that feature many meteors impinging on the Earth at one time. The usual cause for these showers are the trails of debris left by comets. The showers tend to occur at the same time every year, and have their greatest concentration at the same point in the sky. They are therefore often designated by a name referring to the constellation in which they appear. For instance, the meteor shower Taurids has its greatest concentration of meteors in the constellation Taurus between November 1-7, and is caused by the comet Encke.

THE TERRESTRIAL PLANETS

EARTH

Earth

A. The Earth formed in the inner solar nebula. It passed through the four stages of planetary development that other solid planets also experience to varying degrees. These four stages are:

1. **Differentiation:** The earth was originally molten, at which time matter seperated according to density: the heavier iron sank to the core, while the lighter silicate minerals "floated" to the surface, thus forming the crust.
2. **Cratering:** The solid surface is bombarded with debris from the solar system.
3. **Flooding:** Decay of radioactive elements heats planet's interior, causing lava to well up through fissures in the crust and flood deeper basins. As the planet cools, water falls as rain and floods basins to form oceans.
4. **Surface Evolution:** Plate tectonics and erosion change surface features slowly.

B. The Earth's interior is **differentiated**. Because the density of the entire earth is 5.52 g/cm^3, and the crust is much less dense, the interior is made of very heavy elements. It is divided into four areas.

1. The **crust** is very thin relative to the radius of the Earth, only 35-60 Km deep. In fact, with respect to the size of the Earth, it is proportionally thinner than the skin on an apple.
2. The **mantle** is a layer of dense rock, which is very hot, and under a lot of pressure. The heat and pressure make the rock plastic, or malleable. The mantle is denser than the crust, which floats on it. As the mantle moves, the crust floating on it also moves, causing earthquakes.
3. The core has <u>two</u> regions, a **liquid core** and a **solid core**. The interior of the planet can be explored by monitoring shock waves from earthquakes. As the surface crust is dislocated, the shock of the motion spreads through the Earth. There are two types of waves that result. **S-waves** are shaking waves, like the shaking of jello. **P-waves** are pressure waves like sound waves. P-waves will travel through all materials, but S-waves only travel through solids. When an earthquake strikes one part of the Earth, S and P waves are felt nearby, but P-waves are also felt on the other side of the Earth. Therefore, the center of the Earth must be liquid. This liquid core is made of molten iron and nickel and has a density of about 14 g/cm^3, compared to 3.0 g/cm^3 for the crust and 4.4 g/cm^3 for the mantle. In the inner core, the pressure is so great that the iron and nickel become solid again.

C. **Plate tectonics** is the process by which the crust of the planet changes. The plastic mantle, which is always moving due to convection currents, causes the plates to move and rub against one another. A region where one plate is forcing another downward is called a subduction zone.

D. The Earth's atmosphere is called a **secondary atmosphere**. That is, the Earth did not have the atmosphere it has now when it was originally formed. The primeval atmosphere was rich in carbon dioxide, nitrogen and water vapor. During the flooding stage of planetary development, volcanoes bellowed up large amounts of gasses. The carbon dioxide was dissolved into the Earth's oceans and turned into carbonate rocks, thus removing it largely from the atmosphere. The atmosphere received its oxygen from green plants.

E. The Earth wobbles a tiny amount in its rotation about its axis. This wobbling is called **precession**, and takes about 26,000 years to complete one circle.

F. The **Earth's moon** is unique in the solar system in that it is so large relative to the Earth.

Earth's Moon

There are larger moons, but they are orbiting proportionally larger planets. Therefore, the origin of our moon has been the focus of considerable debate. There are three modern theories of the origin of the moon. They are:

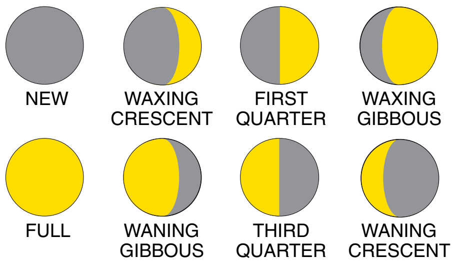
1. **Capture Theory:** The moon was captured by the gravitational field of the Earth, but this would not explain why the moon orbits the Earth in the same plane as the Earth orbits the sun. Many moons of other planets appear to be captured satellites, but they are very small and have very odd orbits.
2. **Twin Theory:** The moon formed alongside the Earth during its early development. However, one would then expect the Earth and moon to be made of the same material, which they are not.
3. **Impact Theory:** The early Earth was impacted by a large object, perhaps the size of Mercury. It then jettisoned a large amount of exterior material into space. This theory explains why the moon is made of mostly lighter material than the Earth, and why it is so large. The impact theory is now the most widely accepted.

The moon has several notable surface features. The first is its craters. These craters indicate that the moon does not have an atmosphere (otherwise the craters would have long ago eroded due to atmospheric conditions such as wind), and that the moon is not tectonically active. Each crater is named for a scientist, i.e., the Tycho Brahe crater and the Kepler crater. The dark regions on the moon are called **Maria** (Mare is Latin for sea), and each dark region is so named, i.e., the Sea of Tranquility, the Sea of Storms. The Maria are made of newer, heavier material than the lighter, highland regions. They are therefore thought to be congealed lava pools created by large impacts. The highland regions are the light areas of the moon and are mostly made of anorthosite, which is a lighter but older type of rock.

G. **Eclipses**

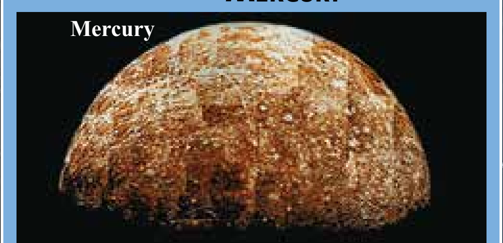
1. A **lunar eclipse** is when the earth casts its shadow on the moon.
2. A **solar eclipse** is when the moon casts its shadow on the earth, blocking our view of the sun.
3. These two types of eclipse often happen about two weeks apart, that being the time it takes the moon to travel from one side of the Earth to the other. Eclipses do not happen every month because the plane in which the moon orbits the Earth is inclined by 5° to the plane in which the Earth orbits the sun. Therefore, the shadow of the moon is usually above or below the Earth, and the shadow of the Earth is usually above or below the sun.
4. When one type of eclipse happens, the other will usually happen soon after. This is called an **eclipse season**, and happens somewhere on Earth at least once a year.

H. The moon orbits the Earth every 27.322 days. This is called the moon's **sidereal** (with reference to the stars) **period**. Because the Earth is revolving around the sun, however, it takes the moon 29.53 days to go through its phases as seen from Earth. This is called its **synodic** (with respect to the sun) **period**. There are eight names for the phases of the moon. A **new moon** is completely dark. Next comes **waxing** (growing brighter) **crescent** (1/4 lit), **first quarter** (1/2 lit), **waxing gibbous** (3/4 lit) and **full**. A full moon is completely lit. After the full moon the phases are **waning** (growing dimmer) **gibbous** (3/4 lit), **third quarter** (1/2 lit) and **waning crescent** (1/4 lit).



I. The **tides** are caused mostly by the moon, and moderately by the sun. The moon's gravity pulls on the Earth, causing a bulge of water. The Earth then spins beneath this bulge of water, causing the tides. Because there is a bulge at the side of Earth facing the moon, and the exact opposite side facing away from the moon, there are two high tides and two low tides every day. When the moon and the sun are working together to make very big tides, the effect is called **Spring Tides**. When they are working against one another (at right angles to one another) to produce very small tides, the effect is called **Neap Tides**.

Mercury


Mercury

A. Mercury is named after the Roman messenger of the gods. Mercury is intermediate in size between the Earth and the moon. It orbits very close to the sun and so is hard to see. In photographs, Mercury looks like the moon, in that it is heavily cratered and has no atmosphere. Although it is closest to the sun, Mercury is not the hottest planet. That distinction belongs to Venus. However, Mercury does have the largest temperature differences of any planet, varying from -170° C to 430° C.

B. There is a large impact crater on Mercury called the **Caloris Basin**. On exactly the opposite side of the planet, there is an area, where the shock waves converge known as the **weird terrain**.

C. Mercury is made mostly of iron. The percentage of iron in the core of the planet indicates that it may have been hit in its early developmental stages by a very large object. This impact could have dislodged much of the lighter materials constituting the planet, and left it as the small iron sphere it is today. The planet also has long curved ridges called **lobate scarps**. These cliffs are wrinkles on the surface caused by the slow cooling of the iron core.

D. Mercury has an odd rotation about the sun. It rotates on its axis one and a half times for each orbit around the sun. That means there are three days in every two years on Mercury. Furthermore, the orbit of Mercury about the sun is notable in that it is very elliptical.

Venus

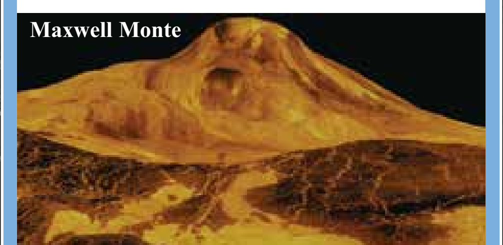

Radar Image of Venus

A. Venus is named after the Roman goddess of love. It is the planet closest in size to Earth. It is shrouded in a deep layer of clouds that reflect light very well. It is therefore a very bright object in our sky. Because they orbit very close to the sun, Mercury and Venus are called morning and evening "stars" as they can only be seen in the morning or evening. Aside from the sun and the moon, Venus is the brightest object in our sky.

B. The surface of Venus is often compared to the biblical notion of Hell. It is very hot (475° C), the air pressure is almost 100 times that of Earth, and it often rains sulfuric acid. The atmosphere is almost entirely carbon dioxide, which creates a **greenhouse effect** some 300,000 times that of Earth's. This is the cause of the intense heat. The atmosphere is also a secondary atmosphere. Its origin is in the plentiful volcanic eruptions on the planet. These eruptions can be seen indirectly from Earth since they spew large amounts of ions into the atmosphere, which tend to cause enormous lightning storms.

C. The surface of Venus is so hot that periodically the outer crust may melt. From radar images of the surface, it can be seen that there are many volcanoes. The surface is roughly divided up between 65 % low rolling plains, 25 % highlands, with the rest being volcanic areas. There are two major highland, or mountainous areas, **Ishtar** and **Aphrodite** (Ishtar is the Babylonian goddess of love, and Aphrodite, the Greek). Ishtar is about the size of Australia and Aphrodite is approximately the size of South America.

D. Although Venus has many volcanoes, there is no evidence of plate tectonic activity. The currents in the mantle are deforming the crust, and forming large surface bulges, called coronae, and mountains, such as the **Maxwell Monte**, which are almost twice as high as Mount Everest.


Maxwell Monte

E. Venus is unique in the solar system because it spins, when viewed from a perspective looking down on Earth's North Pole, in a clockwise direction. All of the other planets, except Uranus, exhibit a counter-clockwise rotation with respect to our North Pole. This odd rotation makes Venus the slowest rotating planet, and contributes to its meteorological patterns. An impact with a large object was probably the cause for this aberrant behavior.

Mars


Mars

A. Mars is named after the Roman god of war. It is about half the size of Earth, with about one-tenth the mass. In some ways, Mars is much like the Earth. It has a similar rotational period, and its yearly orbit is only twice that of Earth's. However, Mars is much colder than Earth, and its small size has affected its ability to retain an atmosphere.

B. Mars' atmosphere is very similar in composition to that of Venus, but much thinner. It is thinner because Mars has a very small gravitational field, and hence cannot hold onto light gasses. The thin CO_2 atmosphere therefore does not contribute greatly to any greenhouse effect. Mars does have polar ice caps which are composed of a combination of water ice and carbon dioxide ice (dry ice).

C. The **dried-out river channels** on Mars give evidence that Mars did in fact once have water on its surface. When Mars was cooling after its initial formation, water vapor was probably out-gassed. The water then condensed into clouds and rained down to the surface to form rivers and lakes. In addition, large quantities of water could have been released in the form of mudslides and the like. The lack of an ozone layer, however, means that the water molecules could be easily broken up into their constitutive elements, and these gasses could escape Mars' small gravitational field. Therefore, Mars now has no water existing in the liquid state. However frozen water exists in the polar ice caps and as permafrost beneath the surface.

D. Mars has a very thick outer crust. This determines many of its geological features. The largest volcano in the solar system is on Mars, the **Olympus Mons**. Its base is approximately the size of the state of Missouri, and it is more than twice as tall as the largest volcano on Earth. The largest valley in the solar system is also on Mars. In a region called **Tharsis**, a massive bulge about 10 Km above the surface has formed. Near this bulge is the **Valles Marineris** (named after the **Mariner Space Probe** which discovered it). The Valles Marineris is long enough to reach from New York to Los Angeles, and is at some spots, over 4 miles deep. The Tharsis bulge and the Valles Marineris are thought to be causally related to one another.

E. Mars is red because it has a great deal of oxidized iron on the surface; i.e. because it is rusty.

F. Mars has two small moons, **Phobos** (fear) and **Deimos** (panic). Diemos is the smallest cataloged satellite in the solar system.

Comparative Data on the Terrestrial Planets

Quantity	Earth	Mercury	Venus	Mars
Equatorial diameter (Km)	12756	4878	12104	6794
Density (kg/m^3)	5517	5500	5250	3933
Mass (Earth=1)	1.0	0.055	0.815	0.107
Surface gravity (Earth=1)	1.0	0.38	0.903	0.38
Escape velocity (km/s)	11.2	4.3	10.36	5.03
Mean distance from sun (Au)	1.0	0.3870987	0.7233322	1.5236915
Mean distance from sun (miles)	9.3×10^7	3.599×10^7	6.7239×10^7	1.4136×10^8
Mean distance from sun (10^6Km)	149.6	57.9	108.2	227.9
Orbital period (Earth years)	1.0	0.241	0.615	1.88
Orbital period (Earth days)	365.24	87.97	224.68	686.95
Orbital velocity (Km/sec)	29.79	47.89	35.03	24.13
Ave. Surface Temperature (K)	280	400	730	210

THE JOVIAN PLANETS

JUPITER

A. Jupiter is named after the Roman king of the gods. It is more than twice as massive as all the other planets in the solar system combined.

B. It is a giant ball of hydrogen-based gasses, whose density is only slightly greater than water. Its surface features many alternating bands of clouds that spin in opposite directions. White bands are known as **zones**, dark bands are known as **belts**. They are caused by material rising from, and falling to, the interior of the planet. The risings and fallings are due to convection currents within the planet. The **coriolis effect** on the surface causes the winds to spin in opposite directions. Organic chemicals cause the color of the belts.

C. The **Great Red Spot** on Jupiter is caused by winds spinning in opposite directions on the surface - essentially a permanent hurricane.

D. It has no surface per se. As one descends through the clouds, they become increasingly dense. At a certain point, they are so dense, they are essentially liquid.

E. It gives off twice as much energy as it receives from the sun. This energy is probably residual heat from the formation of the planet.

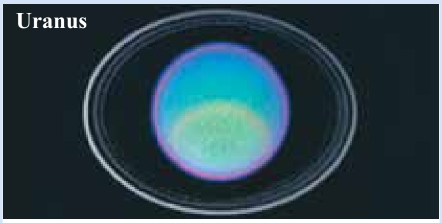
F. Jupiter has 16 named moons. The four largest can be seen easily from Earth, and are known as the Galilean satellites.

1. **Io** is particularly interesting, as it is extremely volcanically active. The enormous gravitational field of Jupiter pulls and distorts Io to such an extent that internal friction heats up the moon. The internal heat manifests itself in volcanic activity, which produces sulfur, making the surface of the moon look reddish-orange.
2. **Europa**, the next moon out, contains an icy crust covering a mantle of liquid water. Some planetary scientists think that Europa might be able to harbor life. Its surface has recently been found to be covered with a great deal of epsom salts.
3. **Ganymede**, the next moon, is the largest moon in the solar system, and is in fact larger than the planet Mercury.
4. **Callisto**, the last Galilean moon, is similar in composition to Ganymede, but not quite as large. The moons of Jupiter formed in such a way as to mimic the formation of the solar system. The small rocky moons formed towards the interior of the planetary nebula, and the larger, lighter moons formed further out.

G. Jupiter, as well as all of the Jovian planets, has rings. However, its rings are not as large or as visible as those of Saturn. The rings were not discovered until spacecraft were able to image the planet from behind, so as to see the rings in relief.

H. Jupiter exhibits **differential rotation**, in which the equator of the planet spins faster than the north or south poles. Only a planet made essentially out of gas could do this. All of the Jovian planets exhibit this feature.

URANUS



A. Uranus is named after the Roman god of the sky. Uranus was discovered in 1781 by Sir William Herschel by careful observation of the heavens. He saw an object in his telescope which was disk-shaped and too large to be a star. After several months it became apparent to astronomers that this was a planet because it moved against the background stars but didn't grow a tail like a comet did.

B. It is a relatively featureless, pale blue planet. It lacks the cloud bands that are distinctive on the surface of Saturn and Jupiter. Part of the reason for this is it has a rotation about its axis that is almost in the plane of its orbit. In other words, whereas most planets, including Earth, spin almost directly up and down with respect to their orbital path, Uranus has been pushed over on its side and is spinning with its north or south pole occasionally pointing directly at the sun. This rotational pattern keeps Uranus from having a dynamic weather pattern. Half of the planet has almost constant heating for half the year, whereas most planets have the entire planet covered with partial heating over very short periods of rotation. This odd rotation was probably caused by the impact of a large object early in the formation of the planet.

C. Most of the moons of Uranus are named for characters in **Shakespearean plays**. There are moons named after **Juliet** and **Puck**, as well as other famous characters. Two of the moons are named after characters in **Pope's *Rape of the Lock***, **Umbrial** and **Belinda**.

NEPTUNE

A. Neptune is named after the Roman god of the sea. The two largest moons of Neptune are **Triton** and **Nereid**. Triton is the Roman name for mermen, and Nereid the name for mermaids, thus keeping with the oceanic theme. Neptune was discovered simultaneously by English and French astronomers.

B. Neptune is approximately the same size and composition of Uranus, but has a radically different atmosphere. Because it spins vertically on its axis, rather than on its side, it has a more dynamic surface, with the fastest winds in the solar system at well over a thousand miles per hour.

C. It was once seen to have a large **blue spot**, discovered by the Voyager Space Probe, much like the Great Red Spot on Jupiter. However, recent pictures from the Hubble Space Telescope show that this has disappeared.

D. Neptune's moon, **Triton**, joins Saturn's moon, Titan, as the only other moon in the solar system with its own atmosphere. It is the largest of Neptune's many moons.

SATURN

A. Saturn is named after the Roman god of the harvest. It is known for its complex ring system, as well as for its moon, Titan. Saturn is almost as large as Jupiter, but has less than one-third the mass. In a large enough ocean, Saturn would float, as it has an average density of less than one.

B. Saturn lacks the striking banded cloud patterns of Jupiter. The reason is that it is just too cold. Saturn is nearly twice as far away from the sun as Jupiter. The exterior of Saturn is made up of frozen ammonia clouds. The interior is otherwise similar to Jupiter's.

C. Saturn has a large and complex **system of rings**. They may be from several different sources. First, the rings lie at about 2.44 the planetary radii of Saturn. At that distance, it has been calculated that any moon made of a similar substance to the planet will be pulled apart by the gravitational attraction of the planet. The distance is known as the **Roche limit**. Any satellite within this limit will be pulled apart. Additionally, the planet may have captured satellites, and broken them apart. There is a large gap in the rings of Saturn called the **Cassini division**. The gaps in the rings are most probably due to shepherding satellites that orbit in resonance with the rings. The rings are made of myriad individual particles of rock and ice. They are 50,000 miles across and 200 yards deep.

D. Saturn has 22 moons, the most interesting of which is **Titan**. Titan is one of two moons in the solar system with its own atmosphere. Some planetary scientists believe that Titan is one of the most likely places in the solar system for life to be found.

PLUTO

A. Pluto, named after the Roman god of the underworld, is not a Jovian planet. American astronomer **Clyde Tombaugh** discovered the planet in 1930. Pluto's large moon is named after **Charon**, the ferryman over Styx, the river of the dead. Charon is very large compared to Pluto, and in fact it could be said that Pluto and Charon orbit one another, rather than Charon orbiting Pluto. Charon was not discovered until 1977.

B. Not much is known about Pluto because of its small size and vast distance from the sun. It is presumed to be made of mostly frozen gasses and water, similar to most comets, and is thus probably a remnant left over from the formation of the solar system.

COMPARATIVE DATA ON THE JOVIAN PLANETS AND PLUTO

Quantity	Jupiter	Saturn	Uranus	Neptune	Pluto
Equatorial diameter (Km)	142796	120000	50800	48600	3300-2800(?)
Density (kg/m^3)	1330	706	1270	1700	2000?
Mass (Earth=1)	1318.7	743.6	14.6	17.2	0.0025?
Surface gravity (Earth=1)	2.643	1.159	1.11	1.21	?
Escape velocity (km/s)	60.22	32.26	22.5	23.9	?
Mean distance from sun (AU)	5.2028039	9.5388437	19.181843	30.057984	39.4
Mean distance from sun (miles)	4.836x10^8	8.8722x10^8	1.7837x10^9	2.7946x10^9	3.6642x10^9
Mean distance from sun (10^{6}Km)	778.3	1427.0	2869.0	4497.1	5900
Orbital period (Earth years)	11.867	29.461	84.013	164.793	247.7
Orbital period (Earth days)	4334.3	10,760	30,685	60,189	90,465
Orbital velocity (Km/sec)	13.06	9.64	6.81	5.43	4.74
Ave. Surface Temperature (K)	125	95	60	60	40

(Continued from Pluto)

In addition, because Pluto is very cold, the water on it would have a consistency similar to that of steel on Earth.

C. Pluto has a very elliptical orbit, which is inclined to the plane of orbit of the other planets by approximately 17°. This trajectory takes it well away from the path of the other planets. Because of its highly elliptical orbit, Pluto is occasionally closer to the sun than Neptune.

[NOTE: *In August 2006, the International Astronomical Union (IAU) designated Pluto a* ***"dwarf planet"****; debate about planet categories continues into 2007*]

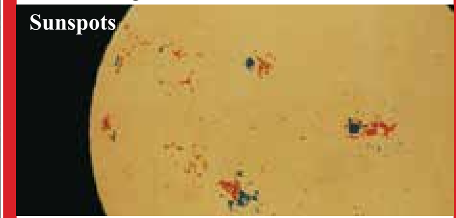
SATELLITES OF PLANETS

Planet	Name of Satellite	Average Diameter in Km
Earth	Moon	3476
Mars	Phobos	24
	Deimos	14
Jupiter	Metis	40
	Adrastea	40
	Amalthea	170
	Thebe	100
	Io	3630
	Europa	3140
	Ganymede	5260
	Callisto	4800
	Leda	15
	Himalia	185
	Lysithea	35
	Elara	75
	Anake	30
	Carme	40
	Pasiphae	50
	Sinope	35
Saturn	Pan	20
	Atlas	30
	Prometheus	100
	Pandora	90
	Janus	190
	Epimetheus	120
	Mimas	380
	Enceladus	500
	Tethys	1050
	Telesto	25
	Calpyso	25
	Dione	1120
	Helene	30
	Rhea	1530
	Titan	5150
	Hyperion	255
	Iapetus	1440
	Phoebe	220
Uranus	Cordelia	25
	Ophelia	30
	Bianca	45
	Cressida	65
	Desdemona	60
	Juliet	85
	Portia	110
	Rosaline	60
	Belinda	68
	Puck	155
	Miranda	470
	Ariel	1160
	Umbrial	1170
	Titania	1580
	Oberon	1520
Neptune	Naiad	60
	Thalassa	80
	Despina	150
	Galatea	160
	Larissa	190
	Proteus	420
	Triton	2700
	Neried	340
Pluto	Charon	1200

THE SUN

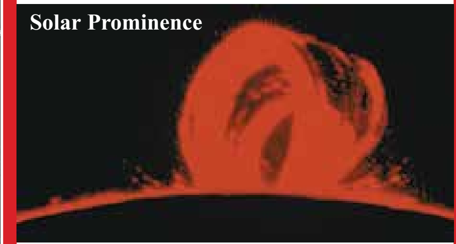
A. The **sun** is the closest star to the Earth. It is a giant ball of gas without any solid surface. When we look at the sun we only see the surface. The processes that take place in its interior determine the various aspects of the sun's surface. There are three primary parts to the sun's surface: the photosphere, the chromosphere and the corona.

1. The **photosphere** is the visible surface of the sun. It is not a solid surface, but made of a layer of glowing gas about 500Km deep. It has a temperature of approximately 6000K. It is actually a collection of many small cells. This pattern of bright cells surrounded by darker regions is called **granulation**. The cells are caused by heated gases rising from the center of the sun, cooling off, then going back down. This type of motion is called a convection current.
2. The **chromosphere** lies above the photosphere, and is a layer of gas approximately 10000 Km deep. It is about 1000 times less bright than the photosphere, and so can only be seen during a solar eclipse. The chromosphere contains elongated flame-like structures called **spicules**, which last for 5 to 15 minutes. These spicules appear to be cool regions extending up into the much hotter corona.
3. The sun's atmosphere above the chromosphere is called the **corona**, from the Greek word for crown. It extends as far as twelve solar radii from the surface of the sun. It has a temperature of between 500,000 and 2,000,000 K. The density of the gas in the corona must be very small for the atoms to attain such temperatures and not emit a great deal of blackbody radiation. The outer corona is so hot and the particles move so fast that the sun cannot hold them in its orbit. The vast streams of particles that leave the surface of the sun are called the **solar wind**. It contains mostly protons and electrons, but also carries heavier particles. The particles of the solar wind that are caught in Earth's magnetic field cause the auroras that light up the northern and southern skies. The particles travel like beads on a wire, and converge where the magnetic field lines converge, at the north and south poles, to create disturbances in the atmosphere that then glow in brilliant colors.



Sunspots

B. **Sunspots** are regions of intense magnetic activity on the surface of the sun. The sunspots actually glow very brightly, but compared to the photosphere, they are cooler by 1000 K and are relatively dark. Sunspots form in pairs, one acting like the positive pole of a magnet, the other acting like the negative pole. Galileo, who saw the sunspots traversing the surface, found the first evidence that the sun rotated on its axis. The sun rotates on its axis every 25 days. Sunspot activity peaks and ebbs on an eleven-year cycle. The eleven-year cycle is explained as a result of the sun exhibiting differential rotation. The equator rotates faster than the North or South Poles. Therefore, the magnetic fields get wound up and tangled. When the fields burst through the surface, they form sunspot pairs. Every eleven years, the sunspots reverse the direction of the magnetic points. This theory of how sunspots form is called the **Babcock model**.



Solar Prominence

C. A **solar flare** is a violent eruption on the surface of the sun. Flares can release as much energy as one billion atomic bombs, and can reach many times the Earth's radius out into the solar system. Their shape is determined by magnetic fields on the surface of the sun.

D. A **solar prominence** is a large archlike or eruptive stream of gas.

E. Planetary Configurations

1. An **inferior** planet is one with an orbit inside that of Earth, i.e., a planet that orbits the sun with a radius less than that of Earth. A planet is in **inferior conjunction** when it is directly between the Earth and sun.
2. A **superior** planet is one with an orbit outside of Earth. A planet is in **superior conjunction** when it is directly on the opposite side of the sun from the Earth. A planet is in **superior opposition** when the Earth is directly in-between the planet and the sun.
3. An **inferior** planet will experience points on its trajectory that take it as far from the sun as can be seen from an Earth viewer's perspective. These points are known as the **greatest eastern and western elongations**.

STARS

ATOMS

A. Atoms are composed of **protons**, **neutrons and electrons**. The protons and neutrons are in the center of the atom, called the nucleus. The electrons spin in a cloud about the nucleus. Protons have a positive electric charge, electrons have a negative electric charge, and neutrons have no charge at all.

B. The number of protons in the center of an atom is called the atom's **atomic number**. Thus, hydrogen has atomic number one; carbon has atomic number 6, and so on.

C. Atoms can be **positively ionized** (more protons than electrons), **negatively ionized** (more electrons than protons), or **neutral** (equal numbers of protons and electrons). The number of neutrons *plus* the number of protons is called the **atomic mass**. Therefore, helium, which has two protons and two neutrons, has an atomic mass of four.

D. All atoms larger than hydrogen and helium have been made within the thermonuclear furnace of a star, powered by **nuclear fusion**. This is the process in which smaller atoms, i.e. hydrogen and helium, are smashed together to form larger **elements**, such as carbon. The fusion process releases energy, which causes stars to radiate light and heat. But fusion only creates atoms up to the size of **iron** (iron has atomic number 26). Atoms larger than iron have been created by another process, the explosion of large stars, called **super-nova**. The energy released in such explosions is enough to create these larger species of atoms.

E. The electrons in atoms only orbit at certain definite levels, like stairs on a staircase. These levels are determined by **Quantum Mechanics**. When light hits an atom, it causes the electrons to jump from a lower stair, or lower energy level, to a higher stair, or higher energy level. The atom only absorbs light if it is of an energy that corresponds to the height between the lower and higher energy level. Similarly, when atoms are very hot and bouncing into one another, their electrons are excited into higher energy levels. When the electrons fall back into their usual energy levels, they only emit light of certain energies, the energies that correspond to the differences between the stairs. Thus, each type of atom has a unique way of absorbing and emitting light. The colors of light that an atom emits are called its **emission spectrum**, and the colors it absorbs are called its **absorption spectrum**.

F. All objects continuously emit light of some wavelength or another. This radiation is usually outside of what humans can see. It is called **blackbody radiation** because it refers to light emitted by an ideal object that is a perfect absorber and emitter of radiation. When objects are hot enough to emit light that is visible to humans, we can easily tell its relative temperature. As the object increases in temperature, it goes from red to orange to yellow to blue. The wavelength of the most common light emitted by the hot object is called the wavelength of maximum intensity. From this wavelength, it is possible to determine the surface temperature of the object.

THE PROPERTIES OF STARS

A. The stars are at such a great distance that normal units of measurement are too unwieldy to use. Therefore, astronomers use **light years** and **parsecs** to denote their distances. A light year is the distance light travels in a year, and is equivalent to about 5.9 trillion miles. A parsec is 3.26 light-years.

B. How bright a star appears to an observer on

Earth is called its **apparent magnitude**. However, stars are at different distances from the Earth, so a measure of how bright they actually are, as opposed to how bright they appear, is needed. This is called **absolute visual magnitude**, which is how bright the star would appear if it were 10 parsecs away from earth.

C. The **luminosity** of a star is the total amount of energy it emits in a second. This is usually stated in comparison to the sun. For instance, the sun has a luminosity of $4x10^{26}$J/sec. The star **Capella** has a luminosity of $4x10^{28}$J/sec. Therefore, Capella has 100 solar luminosities, or is 100 times as luminous as the sun.

D. A star's spectrum can be classified by its light's spectrum. The stars are then given the following classes:
- I. Bright Super-giant
- II. Super-giant
- II. Bright Giant
- III. Giant
- IV. Sub-giant
- V. Main-sequence star

E. **Binary Stars** are stars that orbit one another. Binary stars physically linked to one another by gravity are called **visual binaries**. Binary stars that are not actually linked to one another, but appear to be, are called **optical binaries**. Optical binaries occur when one star is closer to the Earth than another, but they appear from our perspective to be close to one another.

F. **Stellar Densities**: Stars range in density from very tenuous to very, very dense. A very large star may have a density of 0.000001 g/cm^3. Our sun has a density of about 1 g/cm^3, approximately that of water. A white dwarf may have a density of 3,000,000 g/cm^3. At that density, one cubic centimeter would weigh as much as a large truck.

G. **Stellar Evolution**: Stars are powered by a hydrogen-fusion reaction. When the raw fuel for this reaction runs out, its core contracts and heats up, causing the hydrogen fusion shell to ignite. This, in turn, causes the star to expand into a giant star. The contraction of the star's core may ignite the helium that is left there. This helium burn may cause the star to start fusing larger elements. If the star's mass is in the 0.3 to 3 solar masses range, then its helium core will degenerate before the helium ignites. The result is an explosion that is absorbed by the star. The method of evolution of a star depends on its mass.

1. Stars with less mass than 0.4 solar masses will evolve into **white dwarfs**.
2. Stars between 0.4 and 3 solar masses will become **red giants** and then burn out into white dwarfs.
3. Stars as massive as 6 solar masses may lose enough mass to eject planetary nebulae, and then die as white dwarfs.
4. When atoms grow up, they want to be iron. Iron atoms are the most tightly bound of all atomic nuclei. Large stars can fuse atoms as large as iron, but can go no further. When an iron core of a massive star collapses, a supernova is formed, which ejects massive amounts of energy into the surrounding space. Stars that are more massive than 8 stellar masses eventually collapse explosively to produce **supernovae**. Unless the star is larger than about 25 stellar masses, what will be left is a **neutron star**. A neutron star is made by the gravitational fusion of all the electrons and protons of the constituent nova. When neutron stars emit radiation at regular intervals, they are known as **pulsars**.
5. If a star has a mass larger than 25 solar masses, it collapses into a **black hole**. A black hole is a gravitational singularity from which nothing, not even light, can escape. However, black holes may be detected by the radiation emitted from objects falling into them.

STARLIGHT

There are three kinds of spectrums that interest astronomers.

A. **Continuous Spectra**: The surface of a star is heated to such an extent that it glows with a particular color. Red for cool stars, bluish-white for very hot stars. Because the light emitted at the surface has been absorbed and transmitted by many atoms before it reaches the surface, the discrete colors of the atoms' emission spectra have been evened out to form a continuous spectra.

B. **Absorption Spectra**: Are formed when continuous spectra from a star shine through a gas that absorbs only certain colors of light. The absorption spectra, therefore, look like continuous spectra with dark bands at discrete wavelengths.

C. **Emission Spectra**: Are given by gas that is in the outer parts of stars, where the light is not absorbed and emitted many times before being transmitted to space. An emission spectrum is usually just a few colored bands corresponding to the wavelengths of the emitted light.

GALAXIES


Barred Spiral

A. The **Milky Way** is the spiral galaxy in which we live. It has two component parts, the disc and the sphere. The disc is about 100,000 light years in diameter, with the sun about two-thirds of the way out on a spiral arm. The disc stars are thought to be mostly metal-rich population I stars, moving in circular orbits that lie in the plane of the disc. The disc exhibits differential rotation. Those stars near the center orbit the spherical region faster than stars near the perimeter. The spherical component consists of a nuclear bulge at the center and a collection of thinly scattered stars and globular clusters that encircle the disc. These stars are metal-poor population II stars. The size of our galaxy was initially determined by **Harlow Shapley**, and the position of our sun within the galaxy by studying the globular clusters.

B. **Spiral density wave theory** suggests that the spiral arms of galaxies are regions of compression that move through the disc. These are the areas where stars are formed, as gas clouds smash into the compression waves.


Irregular

C. Galaxies are thought to have formed out of spherical clouds of rotating gas. The younger the stars, the more metal-rich they are and the more circular and flat their orbits.

D. The nucleus of the galaxy is invisible at optical wavelengths. Radio and x-ray radiation reveal crowded central features expanding outward.

E. Galaxies are divided into three classes- **elliptical**, **spiral** and **irregular**. Elliptical galaxies used up all of their gas and dust in a sudden burst of star formation when they were young. Spirals formed more slowly, and conserved their gas and dust and thereafter flattened into discs. Irregulars may have formed from turbulent gas clouds.


Spiral

CONCEPTS OF COSMOLOGY

Cosmology is the study of the universe as a whole:

A. The **Cosmological Principle**: any observer in any galaxy sees the same general features of the universe as any other. Based upon:
1. **Homogeneity**: Matter is uniformly spread throughout space.
2. **Isotropy**: The universe looks the same no matter in which direction one looks.
3. **Universality**: The laws of physics that work on Earth work the same in every part of the universe.

B. **Red-Shifted light** from galaxies means that the galaxies are receding from us.
1. **Hubble's Law** shows that the radial velocity of a galaxy is proportional to its distance.
2. This observation is explained by assuming that the entire **universe is expanding**.
   a. A suitable metaphor for this expansion is the "raisin bread model". Assume that you are on a particular raisin. As the loaf of bread expands in baking, the raisins that are closest to you appear to recede. The farther raisins appear to recede even faster. Those furthest away, fastest of all. Yet the bread actually expands at a constant rate. This model, with stars and galaxies as the raisins, and the universe itself as the bread, explains the red shift.

C. **Big Bang Theory**: When the expanding universe picture is run backward, it leads to a point of common origin for all matter in the universe. This point of common origin is the **Big Bang**, where everything in the known universe was created in a single instant. Because time and space also originated in the Big Bang, it is not possible to state that any specific location of space is where the Big Bang occurred. Every point in the universe was there *when* the Big Bang happened. Thus, every point in the universe is *where* the Big Bang happened. The **cosmic microwave background** radiation is the echo of the Big Bang. When the Big Bang occurred, it sent an enormous electromagnetic wave out into the universe. As the universe expanded, the wave itself was stretched-out, much like a phone cord is stretched as you walk away from the base. The stretched-out wave would be very long and have very low energy. Two scientists, **A. Penzias** and **R. Wilson**, discovered this radiation, and we therefore have experimental verification of the Big Bang.

D. There are three alternative theories that deal with the future of the universe.
1. **Big Crunch**: If the universe has a density greater than the critical density, then the collective gravity of all the matter in the universe will cause it to stop expanding and begin to contract. One variation of the Big Crunch theory is that after the universe collapses, it bounces back in another Big Bang. This idea, known as the oscillating universe theory, is not generally accepted because the oscillations would lose a great deal of energy to entropy.
2. **Critical Density**: If the universe has the density $4x10^{-30}$g/cm^3, then the universe will continue expanding forever.
3. **Expanding Universe**: If the universe has a density less than the critical density, which it does according to current scientific theory, then the universe will keep expanding forever.
   a. This leads to the not generally accepted notion of **Heat Death;** wherein, as the universe keeps expanding and cooling off, everything runs out of energy. All the suns will die, galaxies will be gone, etc.

E. **Olber's paradox**: If the universe is static, infinite, eternal and uniformly filled with stars, then why is the sky dark at night? If we look in any direction in the sky, we are bound to be looking at a star, no matter how distant. Hence the nighttime sky should be as bright as the surface of a star. The resolution of the paradox can be found in noting that the assumptions made in the paradox are incorrect. First, the galaxies are all receding from us. Much of their light is red-shifted to the extent that the energy of the light is undetectable. Second, the universe is not eternal; it was created in the Big Bang. Therefore, light from the most distant stars has not had enough time to reach us.

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